National Aeronautics and
Space Administration

EXPLORESPACE TECH

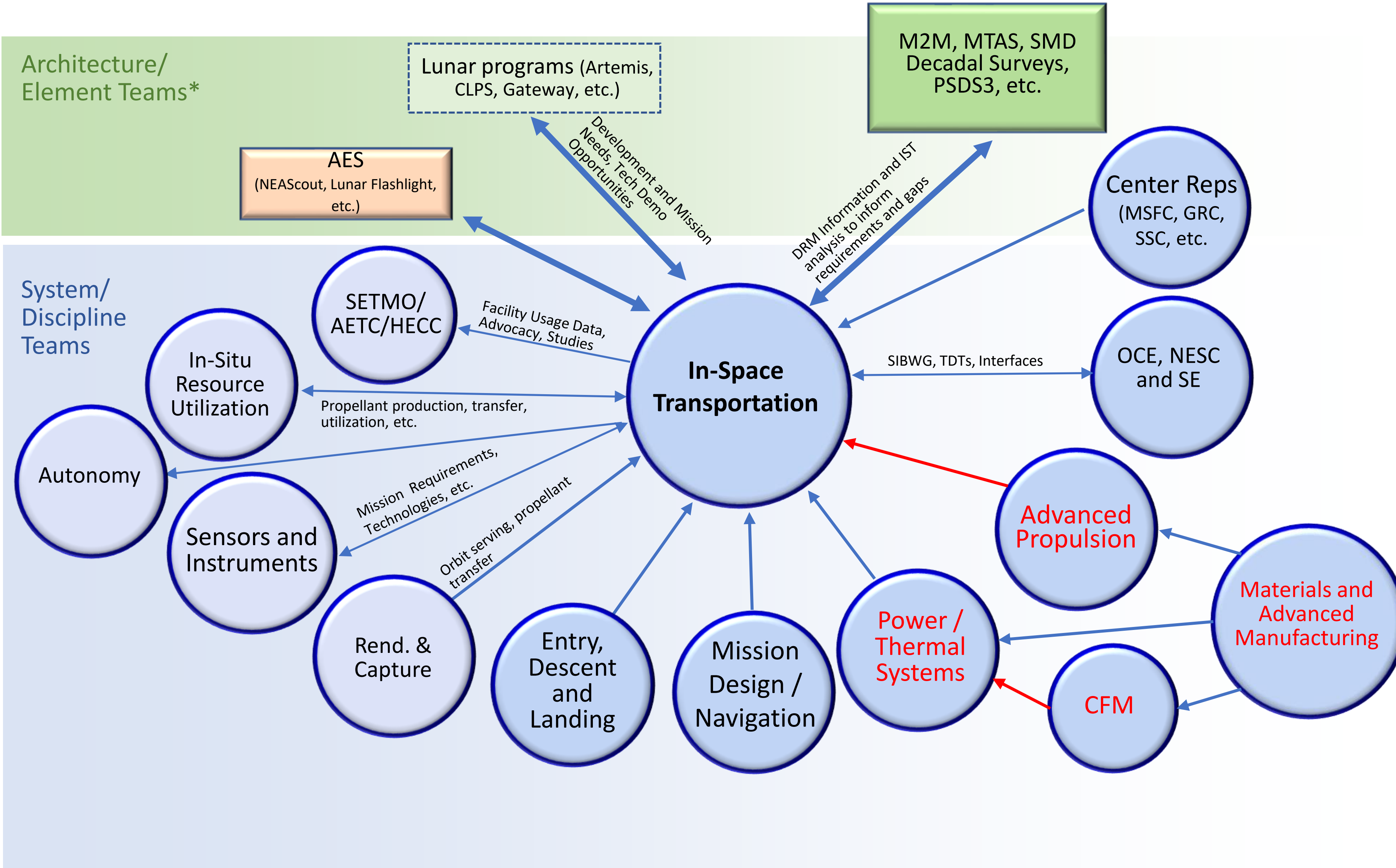
In-Space Transportation

Presentation for the Innovation and Opportunity Conference (IOC)

John Dankanich and Julie Grantier

September 2020

In-Space Transportation – Key Interfaces



*NOTE: Interfaces illustrated are not all inclusive

STMD Strategic Framework

LEAD	THRUSTS	OUTCOMES	CAPABILITIES
Ensuring American global leadership in Space Technology • **Lunar Exploration building to Mars and new discoveries at extreme locations** • **Robust national space technology engine to meet national needs** • **U.S. economic growth for space industry** • **Expanded commercial enterprise in space**	***Go*** ***Rapid, Safe, & Efficient Space Transportation***	• Enable Human Earth-to-Mars Round Trip mission durations less than 750 days. • Enable rapid, low cost delivery of robotic payloads to Moon, Mars and beyond. • Enable reusable, safe launch and in-space propulsion systems that reduce launch and operational costs/complexity and leverage potential destination based ISRU for propellants.	• Advanced Propulsion • Cryogenic Fluid Management
	Land ***Expanded Access to Diverse Surface Destinations***	• Enable Lunar and Mars Global Access with ~20t payloads to support human missions. • Land Payloads within 50 meters accuracy while also avoiding local landing hazards.	• Human & Robotic Entry, Descent and Landing • Precision Landing
	Live ***Sustainable Living and Working Farther from Earth***	• Conduct Human/Robotic Lunar Surface Missions in excess of 28 days without resupply. • Conduct Human Mars Missions in excess of 800 days including transit without resupply. • Provide greater than 75% of propellant and water/air consumables from local resources for Lunar and Mars missions. • Enable Surface habitats that utilize local construction resources. • Enable Intelligent robotic systems augmenting operations during crewed and un-crewed mission segments.	• Advanced life support and human performance • Advanced Materials, Structures and Manufacturing • Advanced Power Systems • In-situ Propellant and Consumable Production • Autonomous Systems and Robotics
	Explore ***Transformative Missions and Discoveries***	• Enable new discoveries at the Moon, Mars and other extreme locations. • Enable new architectures that are more rapid, affordable, or capable than previously achievable. • Enable new approaches for in-space servicing, assembly and manufacturing. • Enable next generation space data processing with higher performance computing, communications and navigation in harsh deep space environments.	• On-orbit Servicing, Assembly and Manufacturing • Small Spacecraft Technologies • Advanced Avionics • Advanced Communications & Navigation

Note: Multiple Capabilities are cross cutting and support multiple Thrusts. Primary emphasis is shown

Revision date: : May 26, 2020

Go

Rapid, Safe, & Efficient Space Transportation

Solar Electric Propulsion (SEP)

Nuclear Propulsion Technologies

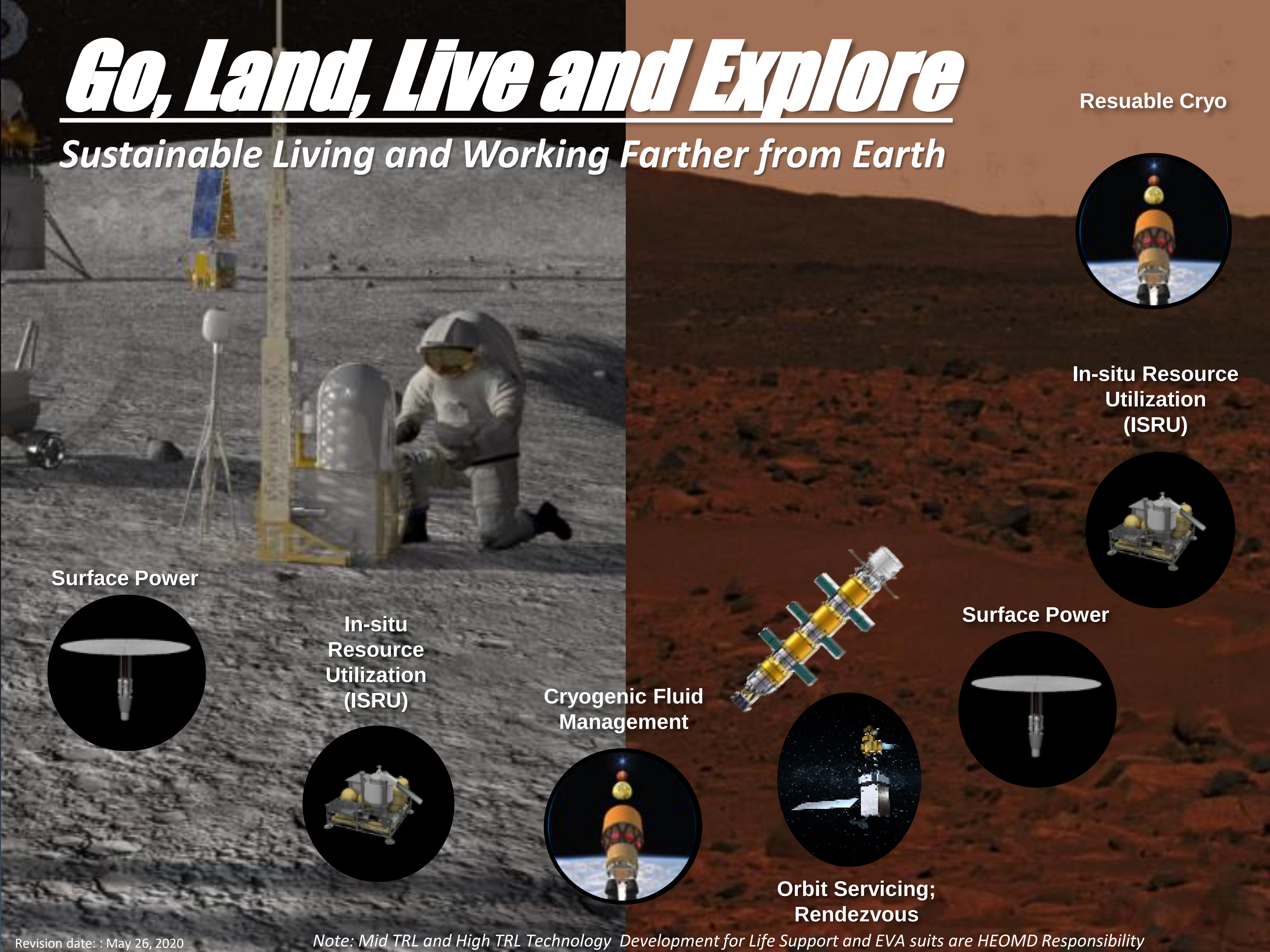
Thruster Advancement for Low-temperature Operations in Space (TALOS)

Cryogenic Fluid Management

Green Propellant Infusion Mission (GPIM)

Rapid Analysis and Manufacturing Propulsion Technology

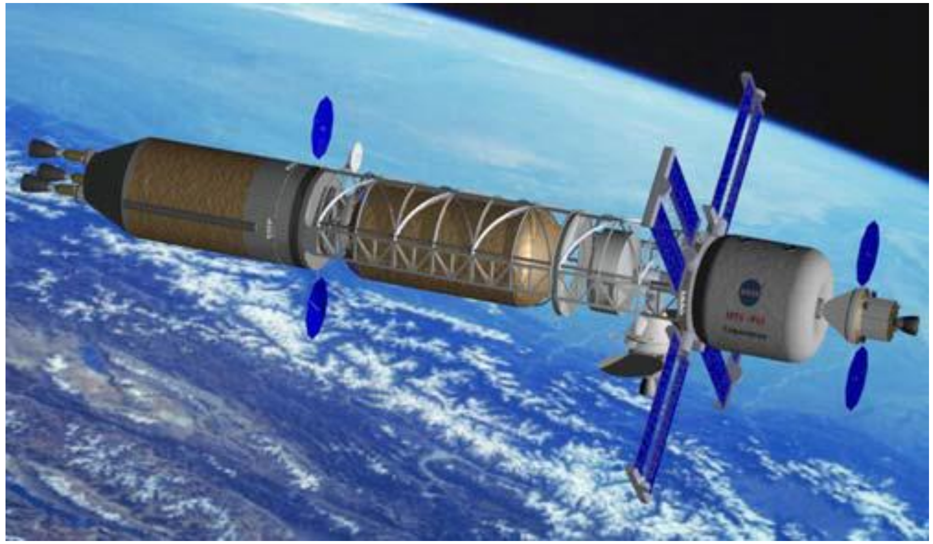
- **Enable Human Earth-to-Mars Round Trip mission durations less than 750 days.**
- **Enable rapid, low cost delivery of robotic payloads to Moon, Mars and beyond.**
- **Enable reusable, safe launch and in-space propulsion systems that reduce launch and operational costs/complexity and leverage potential destination based ISRU for propellants.**



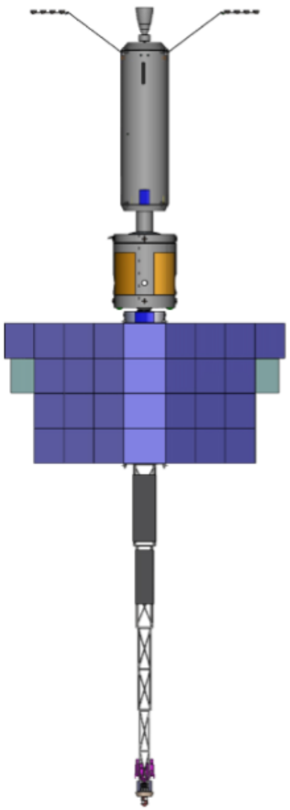
Go, Land, Live and Explore
Sustainable Living and Working Farther from Earth
Resuable Cryo
In-situ Resource Utilization (ISRU)
Surface Power
In-situ Resource Utilization (ISRU)
Cryogenic Fluid Management
Orbit Servicing; Rendezvous
Surface Power
Revision date: : May 26, 2020
Note: Mid TRL and High TRL Technology Development for Life Support and EVA suits are HEOMD Responsibility

Exploration – High Level Transport Element Options

Nuclear Thermal

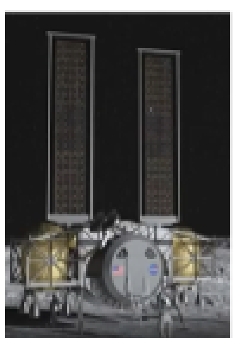


NEP / Chem

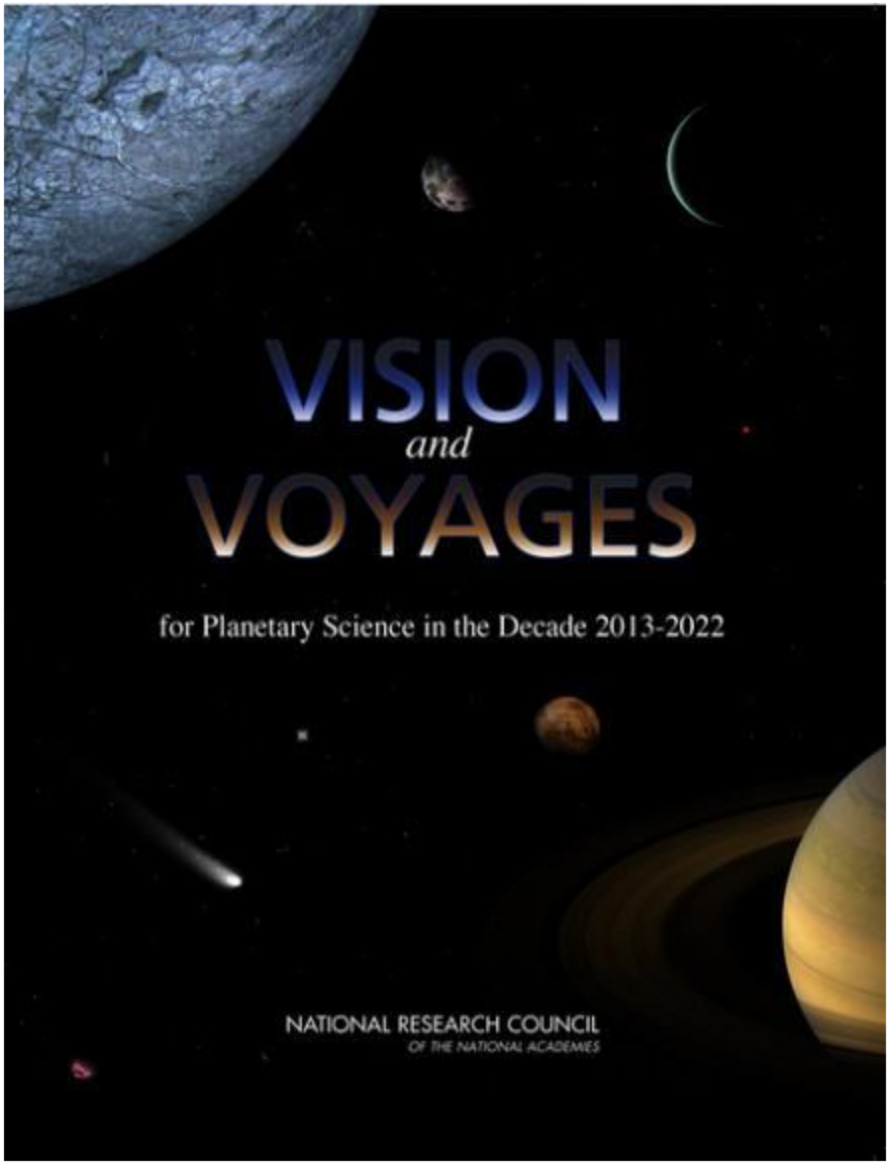


SEP / Chem

Cryogenics



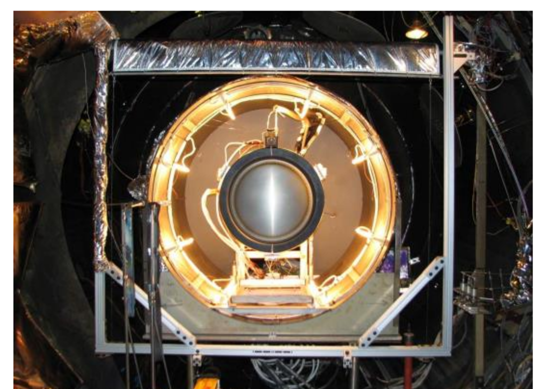
Science – Planetary (Traditional)



Planetary Science and Astrobiology Decadal Survey 2023-2032

Challenging Targets and Environments

- Flagship Solar Electric Propulsion
- Low Temperature Storable Propellants
- Mars Ascent Vehicle
- Radioisotope electric propulsion
- Aerocapture
- Etc.



Science – Planetary (Small Spacecraft)

Planetary Science Deep Space SmallSat Studies

Mars

Robert Lillis, Mars Ion and Sputtering Escape Network (MISEN) ESPA

Luca Montabone, Mars Aerosol Tracker (MAT) ESPA

Michael Collier, PRISM: Phobos Regolith Ion Sample Mission 12U

Anthony Colaprete, Aeolus - to study the thermal and wind environment of Mars 24U

David Minton, Chariot to the Moons of Mars 12U

Venus

Attila Komjathy, Venus Airglow Monitoring Orbiter for Seismicity (VAMOS) ESPA

Valeria Cottini, CUVE - Cubesat UV Experiment 12U

Christophe Sotin, Cupid's Arrow ESPA

Tibor Kremic, Seismic and Atmospheric Exploration of Venus (SAEVe) ESPA

Icy Worlds and Outer Planets

Robert Ebert, JUpiter MagnetosPheric boundary ExploreR (JUMPER) ESPA

Kunio Sayanagi, SNAP: Small Next-generation Atmospheric Probe ESPA

Small Bodies

Jeffrey Plescia, APEX: Asteroid Probe Experiment ESPA

Beau Bierhaus, Ross (formerly CAESAR) 6U

Tilak Hewagama, Primitive Object Volatile Explorer (PrOVE) 6U

The Moon

Charles Hibbitts, Lunar Water Assessment, Transportation, and Resource Mission (WATER) ESPA

Timothy Stubbs, Bi-sat Observations of the Lunar Atmosphere above Swirls (BOLAS) ESPA

Noah Petro, Mini Lunar Volatiles (MiLUV) Mission 6U

David Draper, Irregular Mare Patch Exploration Lander (IMPEL) ESPA

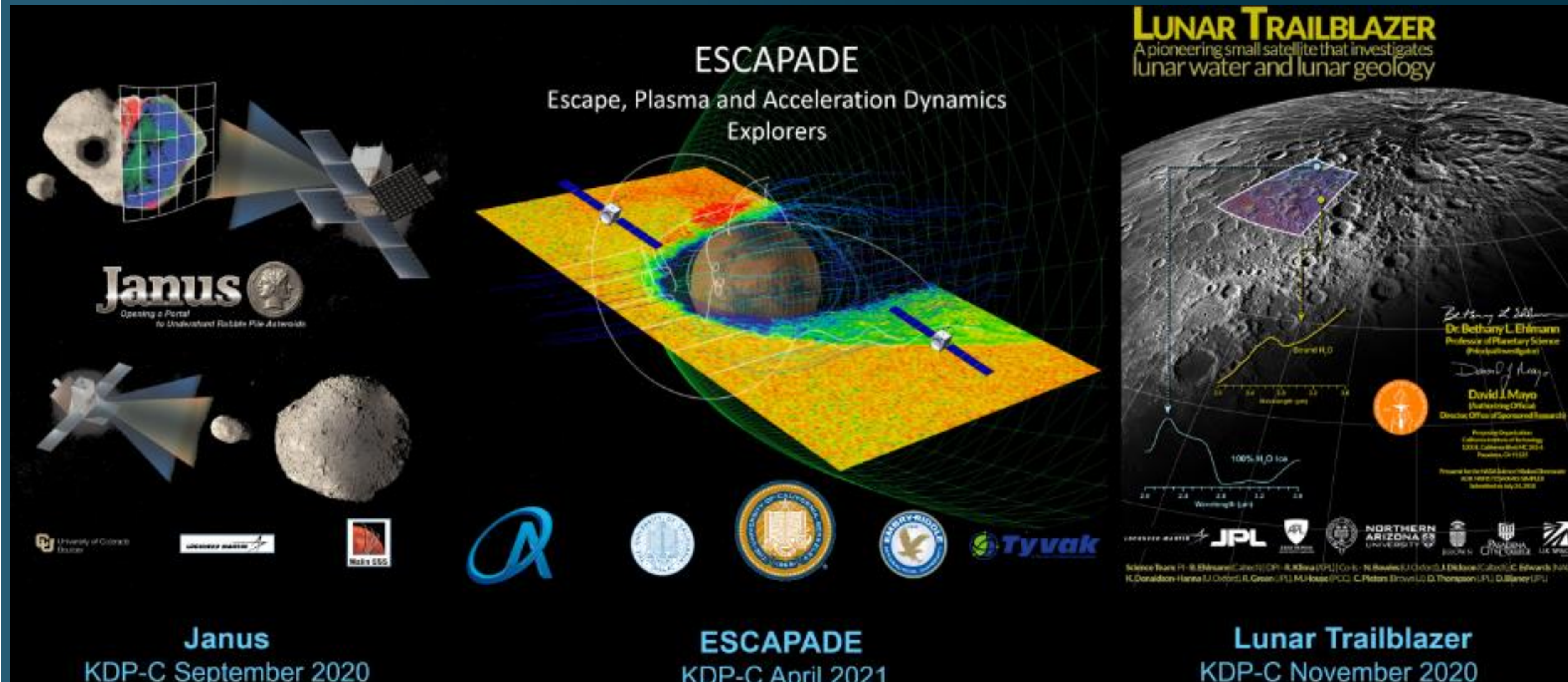
Suzanne Romaine, CubeSat X-ray Telescope (CubeX) 12U

Low Delta-V missions: NEO fly-by, and/or rideshare direct to destination

High Delta-V missions: use electric propulsion

Science – Planetary (Small Spacecraft)

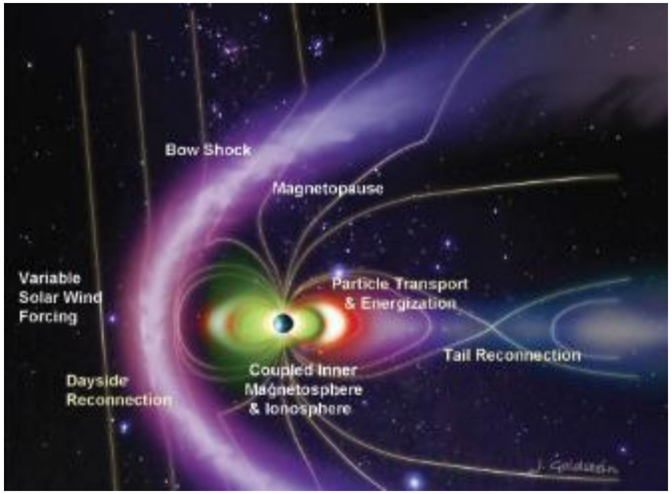
Small Innovative Missions for Planetary Exploration (SIMPLEx-2)

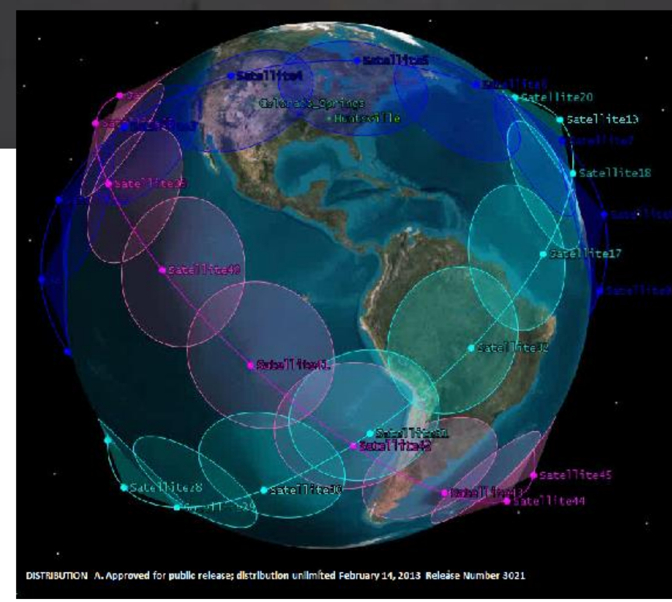


Low Delta-V missions: NEO fly-by, and/or rideshare direct to destination

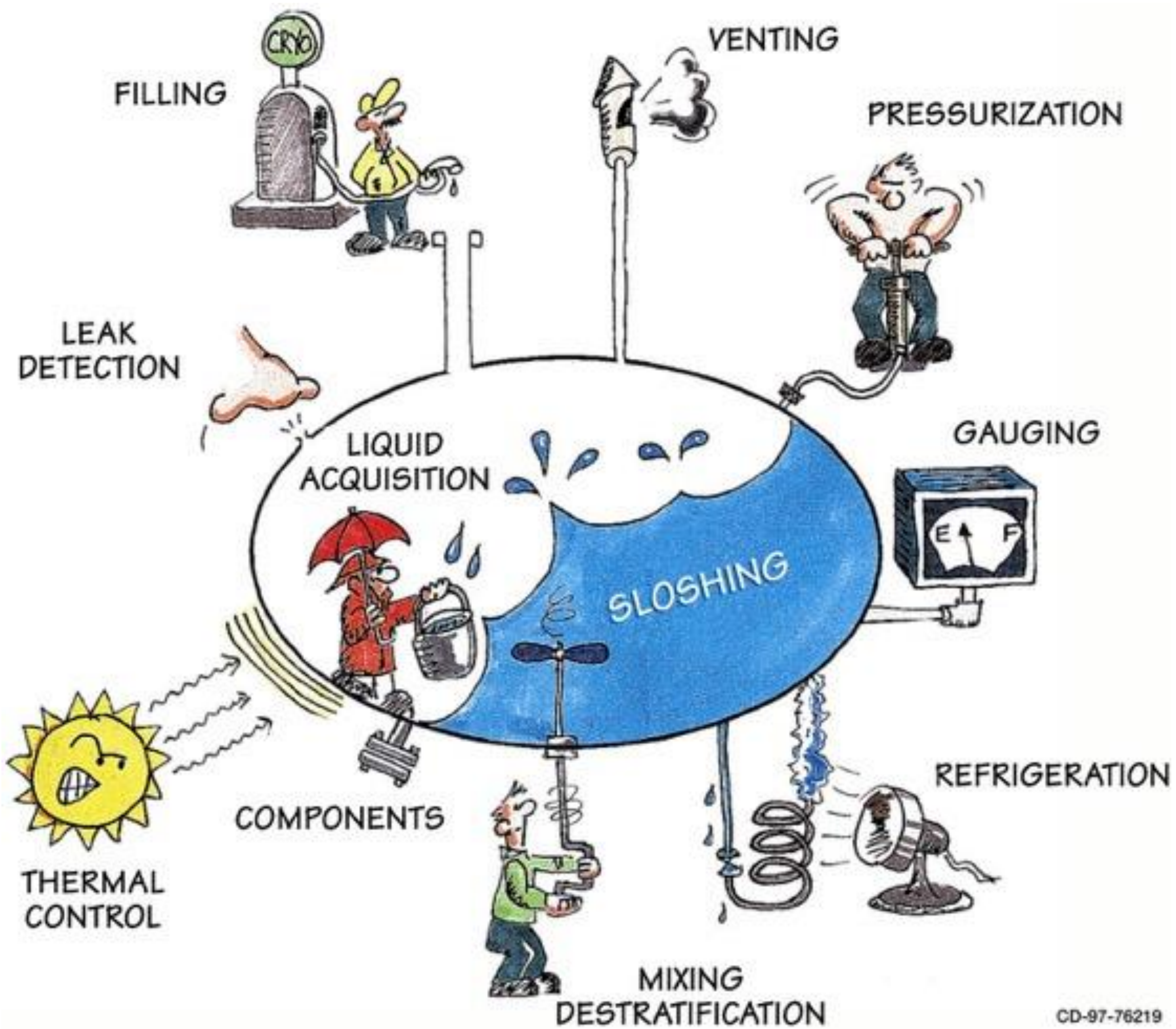
High Delta-V missions: use electric propulsion

Geocentric and/or SmallSat (Government and Commercial)



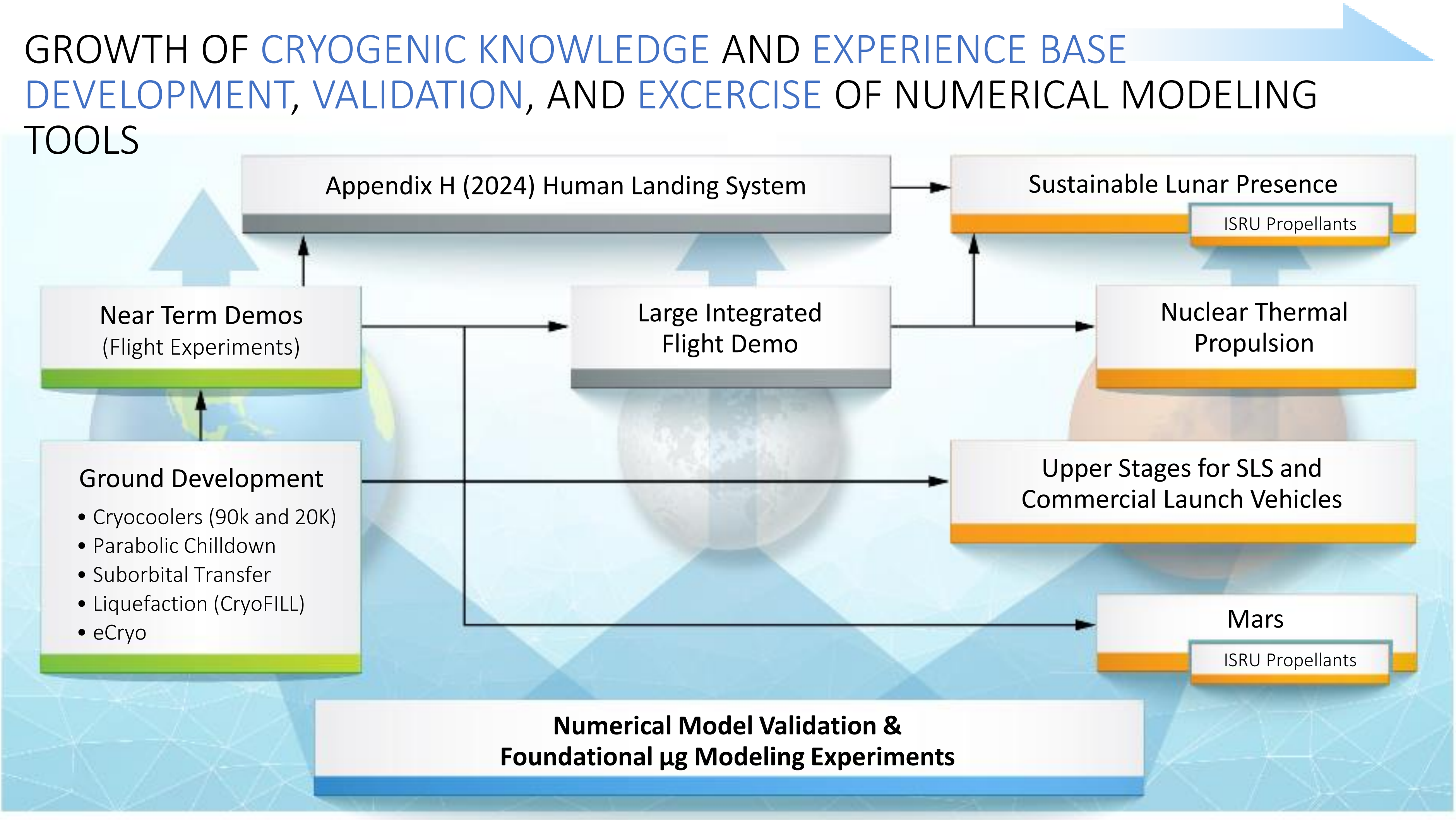



Courtesy of ESA



FILLING
CRYO
VENTING
PRESSURIZATION
LEAK
DETECTION
LIQUID
ACQUISITION
SLOSHING
GAUGING
E
F
THERMAL
CONTROL
COMPONENTS
REFRIGERATION
MIXING
DESTRATIFICATION
CD-97-76219

CFM strategy and End User Applications



Cryogenic Fluid Management (CFM) - Focused

Near Term Subscale Demonstrations to enable an integrated in-space demonstration

Human Landing System (HLS) Investments will impact CFM strategy

- On April 30, NASA selected three U.S. companies to design and develop human landing systems (HLS) for the agency's Artemis program
- All Three companies have upper stages that are Cryo based and likely Cryo lander systems as well.
  - Blue Origin of Kent, Washington, is developing the Integrated Lander Vehicle (ILV) – a three-stage lander to be launched on its own New Glenn Rocket System and ULA Vulcan launch system. **Cryo is LH2/LOX**
  - Dynetics of Huntsville, Alabama, is developing the Dynetics Human Landing System (DHLS) – providing the ascent and descent capabilities that will launch on the ULA Vulcan launch system. **Cryo is CH4/LOX**
  - SpaceX of Hawthorne, California, is developing the Starship – a fully integrated lander that will use the SpaceX Super Heavy rocket. **Cryo is CH4/LOX**

Current CFM Technology Challenges

CFM Elements					
Technologies	Current TRL	Gravity Dependant (Y/N)	Path to TRL 6	"Cross Cutting" or "Fluid Specific"	STP Section
Low Conductivity Structures	6	No	Ground Test	Cross Cutting	2.2.2.3
High Vacuum Multilayer Insulation	6	No	Ground Test	Cross Cutting	2.2.2.2
Sun Shields (deployment mechanism)	5	No	Ground Test	Cross Cutting	2.2.2.3
Tube-On-Shield BAC	5	No	Ground Test	Cross Cutting	2.2.2.1
Valves, Actuators & Components	5	No	Ground Test	Cross Cutting	2.2.2.6
Vapor Cooling	6	No	Ground Test	Fluid Specific	2.2.2.3
Propellant Densification	5	No	Ground Test	Fluid Specific	2.2.2.3
Sub-surface Helium Pressurization in Micro-g	5	Yes	Flight Demo	Cross Cutting	2.2.2.4
MPS Line Chilldown	5	Yes	Flight Demo	Cross Cutting	2.2.2.5
Pump Based Mixing	5	Yes	Flight Demo	Cross Cutting	2.2.2.4
Thermodynamic Vent System	5	Yes	Flight Demo	Cross Cutting	2.2.2.4
Tube-On-Tank BAC	5	Yes	Flight Demo	Cross Cutting	2.2.2.1
Unsettled Liquid Mass Gauging	6	Yes	Flight Demo	Cross Cutting	2.2.2.6
Liquid Acquisition Devices	5	Yes	Flight Demo	Fluid Specific	2.2.2.5
Advanced External Insulation	4	No	Ground Test	Can Be Both	2.2.2.2
Automated Cryo-Couplers	4	No	Ground Test	Cross Cutting	2.2.2.5
Cryogenic Thermal Coating	4	No	Ground Test	Cross Cutting	2.2.2.3
High Capacity, High Efficiency Cryocoolers 90K	4	No	Ground Test	Cross Cutting	2.2.2.1
Soft Vacuum Insulation	3	No	Ground Test	Cross Cutting	2.2.2.2
Structural Heat Load Reduction	3	No	Ground Test	Cross Cutting	2.2.2.3
High Capacity, High Efficiency Cryocoolers 20K	4	No	Ground Test	Fluid Specific	2.2.2.1
Liquefaction Operations (MAV & ISRU)	4	No	Ground Test	Fluid Specific	2.2.2.7
Para to Ortho Cooling	4	No	Ground Test	Fluid Specific	2.2.2.3
Propellant Tank Chilldown	4	Yes	Flight Demo	Cross Cutting	2.2.2.5
Transfer Operations	4	Yes	Flight Demo	Cross Cutting	2.2.2.5
Cryogenic Flow Meter	4	Sometimes	Flight Demo	Can Be Both	2.2.2.5
Autogenous Pressurization in Micro-g*	4	Yes	Flight Demo	Fluid Specific	2.2.2.4

CFM is only as strong as the weakest link

- CFM is a system of several technologies acting together
- The least effective component will drive the performance of the entire system
  - Can’t test one or two CFM technologies at a time, must have a complete system
- To flight test a “transfer” system, most of the “storage” elements must also be in-place in order to have any cryo fluid left when time to perform the actual transfer
- Active cooling (at reasonable scale) is not ready for flight at this time
  - Active cooling at 90 K could be applied to lander class vehicles, larger applications (NTP, ISRU, upper stages, depots) at 90 K and 20 K cryocoolers need further development.

Insulation | Structural Heat | Leak Prevention | Active Cooling (Small scale only) | Pressure Control | Transfer

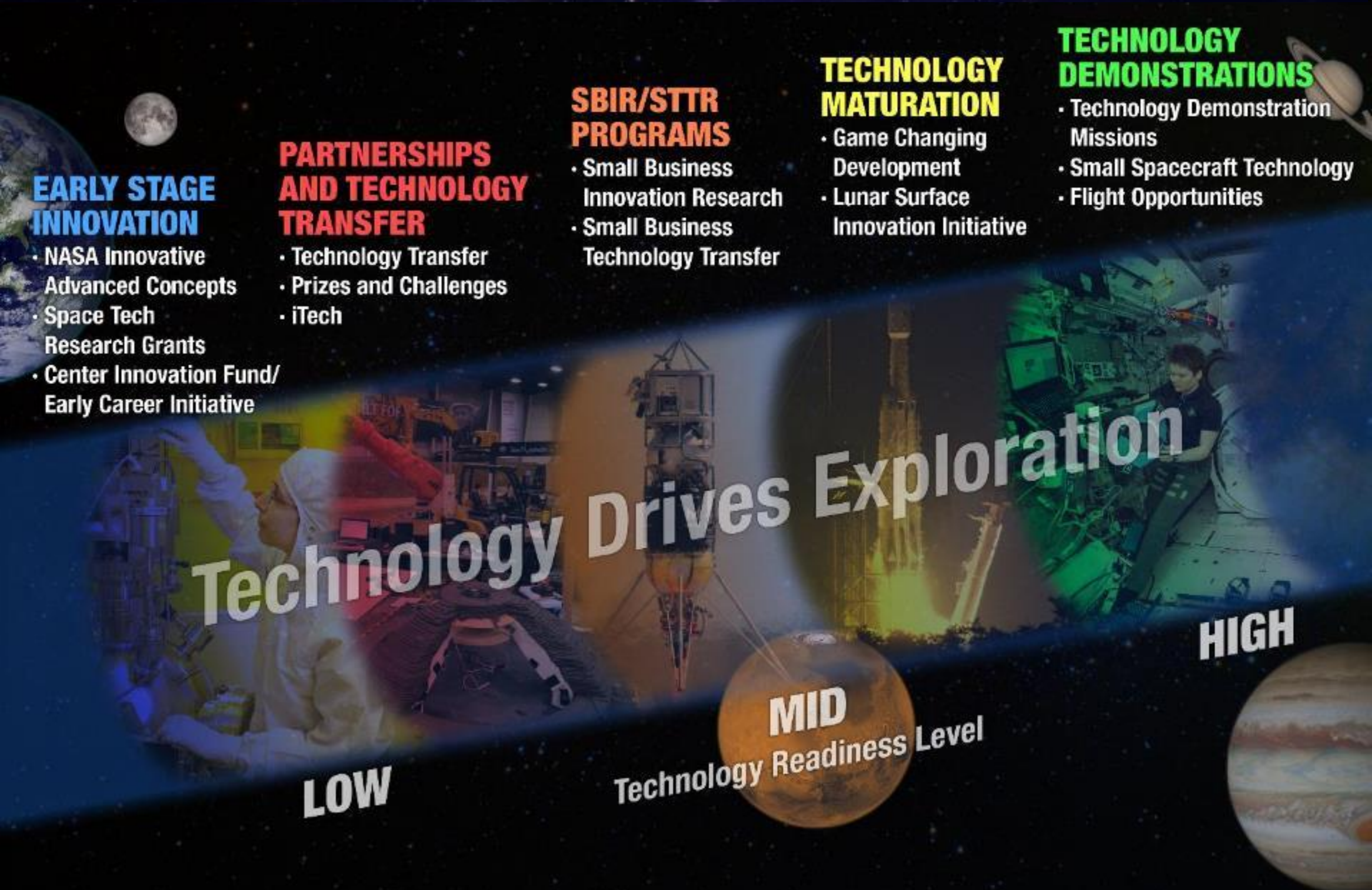
Storage | Transfer

Tracing CFM Technologies to Applications

	Nuclear Thermal Propulsion	Sustainable Lunar Presence	In-Situ Resource Utilization	Advanced Upper Stages	Chemical In-Space
TRANSFER					
Line Chill / Tank Chill	X	X			X
Pump / Pressure Transfer	X	X	X		X
Automated Cryo – Couplers	X	X	X		X
Liquid Acquisition	X	X			X
Valves	X	X	X	X	X
Super – Insulation	X	X	X	X	X
Structural Heat Intercept	X	X	X	X	X
Anchored Modeling	X	X	X	X	X
Pressure Control	X	X		X	X
Active Cooling: Cryo Coolers	X	X	X		X
Active Cooling: Liquefaction			X		
STORAGE					

Core Strategic Risk reduction Path to Enable Integrated Demonstration
Gather Flight data on transfer and storage experiments from subscale demos in micro-g
Initiate flight rated Crycooler design effort (20K and 90K)
Ground Development of Ancillary technologies

Investment Phasing



Summary

- In-Space Transportation (IST) has a wide range of critical technology gaps across multiple disciplines and Strategic Technology Plans.

- IST has heavily leveraged Small Business and Industry investments with multiple enabling technology infusions.

- We will continue to rely on SBIR, STTR and industry investments to close our near, mid and far-term capability gaps.

- Innovative solutions should be proposed with explicit quantified Key Performance Parameter (KPP) expectations relative to the known architectures and reference missions.